One-and Two-Way Coupling of Atmospheric and Hydrologic Models

(Annual Report)

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PROGRESS REPORT
FOR
THE OFFICE OF GLOBAL PROGRAMS

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1. Project Goals

Based on the expectation that global-scale atmospheric models will soon be run at a resolution that allows forecasts of surface climate elements at spatial scales much smaller than the basin size (1000-2000 km^2) used in many operational hydrologic applications, it is important to examine ways in which hydrologic modeling capabilities can be fully integrated within these atmospheric forecast systems. The most appropriate method for achieving this integration is to use the Land Surface Scheme that is coupled to the atmospheric model to directly forecast runoff. To improve hydrological forecasting capabilities, we have designed an interdisciplinary research project with three main questions:

1) How accurately do Land Surface Schemes at sub-catchment (<5 km) resolution simulate runoff when run off-line from atmospheric models?
2) How accurately do nested mesoscale models simulate spatial and temporal variations in surface climate at the sub-catchment (<5 km) scale?
3) When nested versions of mesoscale models are coupled with a sophisticated land surface scheme at sub-catchment (<5 km) resolution, how accurate are the simulations of runoff?

The approach will be to conduct these model tests for two disparate river basins: a mountainous, snowmelt-dominated river basin (the Yampa River, northwestern Colorado) and a flat, rainfall-dominated river basin (Walnut River, Kansas). Both the Yampa and Walnut River basins have micro-meteorological instrumentation that will facilitate off-line simulations with Land Surface Schemes (LSS). In addition the Walnut River is part of the Arkansas-Red River basin in the GCIP Large Scale Area (LSA) - southwest where an extensive (larger-scale) intercomparison of Land Surface Schemes was undertaken (Wood et al., 1998; Liang et al., 1998; Lohmann et al., 1998). Comparisons between the Walnut and Yampa River basins will provide a first step in facilitating transfer of knowledge and experience in the greater Mississippi basin gained during GCIP to more mountainous basins now examined in GAPP. Further studies will be necessary to gain insight into the problems and possibilities in simulating runoff in the wider variety of river basins in the GAPP region.

2. Results and Accomplishments – Current Project Year

2.1 Off-line runs with land surface models

We have compiled and quality-controlled forcing data from micro-meteorological stations in the Yampa and Walnut River basin, and are using these data to perform off-line simulations with a suite of different land surface models. We are currently testing the Community Land Model (Dai et al., unpublished) and the catchment-based LSM (Koster et al., 2000), and plan to use the VIC-3L model (Liang et al., 1994) and the MAPS LSM (which is coupled to MMS in the high-resolution regional climate simulations).

We are comparing the land-surface model simulations against simulations with hydrologic models. The hydrologic model PRMS has been parameterized and calibrated for the Yampa and Walnut River basins using observed climate data. Quingyun Duan (NWS Office of Hydrology) has provided a version of the Sacramento model (Burnash et al., 1973), and this model has been calibrated and tested in the Walnut River basin. Adjustments to PRMS have been made to accept gridded MM5 precipitation, temperature, and solar radiation output at various resolutions. Initial high-resolution regional climate simulations have been provided for the Yampa River basin to CU and USGS (Martyn Clark and Lauren Hay) by the FSL group, and we have begun initial processing of the MM5 output. Hydrologic model runs will proceed very soon.

2.2 High-resolution runs with MM5

2.2.1 FSL Efforts

Simulations with regional climate version of MM5 (Grell et al. 2000) for the period of October 1994 - September 1999 are nearing completion. Simulations are performed in three domains (Fig. 1) with horizontal resolutions of 20, 5 and 1.7 km. High resolution domain is centered on Yampa River Valley. Most significant modifications to the standard version of MM5 include new land-surface model Smirnova et al. (2000) and new ensemble based convection parameterization (employed at 20 and 5 km domains, Grell and Devenyi 2002). Simulations are performed on NOAA/FSL Linux cluster using 64 processors. Execution times for the whole period for the three domains are 1 week, 3 weeks and 3 months, respectively.

Results for 20 km domain were forwarded to Iowa State University.

Currently, simulations are being evaluated against weather analyses with favorable results (Fig. 2) but some improvements to the model might be required with respect to precipitation and snow melt parameterization.

References:

Grell G. A., L. Schade, R. Knoche, A. Pfeiffer, and J. Egger, 2000: Nonhydrostatic Climate Simulations of Precipitation over Complex Terrain. To appear in *J. Geophys. Res*.

Smirnova, T. G., J. M. Brown, and S. G. Benjamin, 2000: Parameterization of frozen soil physics in MAPS. *J. Geophys. Res*., **105 (D3)**, 4077-4086.

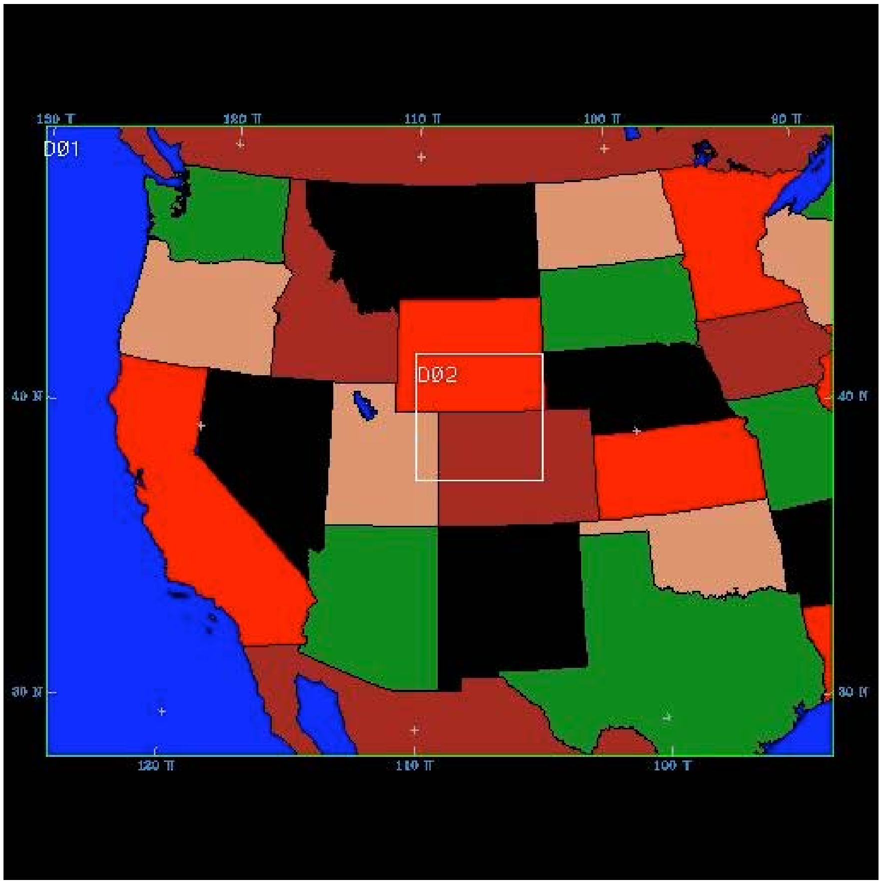

Figure 1: mm5 domains

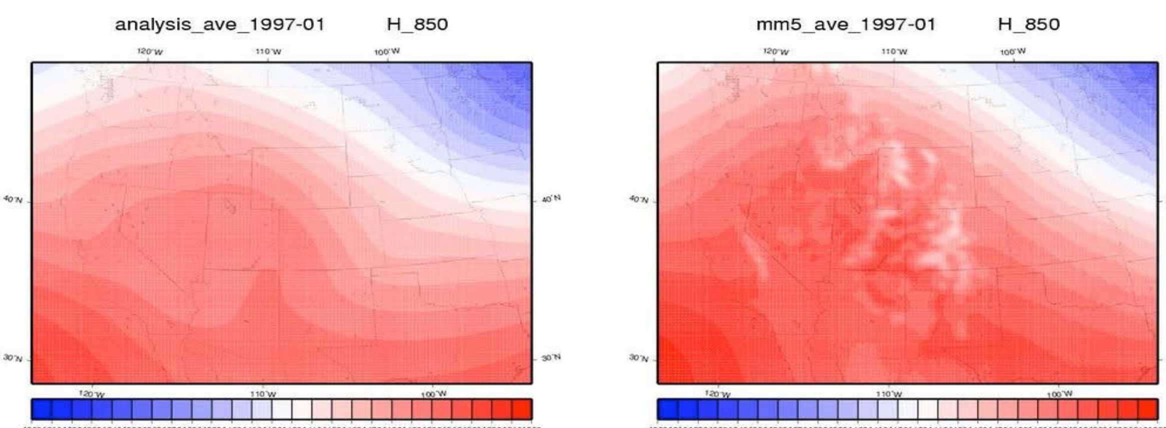

Figure 2: monthly averages for 850mb Geopotential Height for January 1997.

3.1.1 Iowa State Efforts

Attempts during the previous year to engage a graduate student failed when the student, from the Peoples Republic of China, was unable to secure a U.S. visa. Repeated attempts to gain a visa, which included several supporting faxes to the U.S. embassy in China from PI Gutowski, did not succeed. Apparently very few study visas were issued to Chinese males last year. PI Gutowski then found a student at Iowa State who had decided to change the direction of his graduate studies, and this person, David Flory, started working on the project in the spring semester.

Mr. Flory and PI Gutowski implemented simulation using 5-km grid spacing that focuses on the Walnut River basin in Kansas. Specifically, guided by climatological analysis of mesoscale convective systems (Anderson and Arritt, 2001, MWR), we are simulating summer 1997, a period of significant mesoscale convective activity. We have interacted with Georg Grell and Mariusz Pagowski of the Forecast Systems Lab to obtain their version of MM5, used for high resolution simulation of the Yampa River basin (section 2.2.1). Grell and Pagowski also provided output from their western U.S. simulation using a 20-km grid, which gives the initial and lateral boundary conditions for our simulations.

In order to simulate the evolution of traveling convective storms that pass over the Walnut basin, the 5-km grid covers Kansas and small portions of surrounding states with 121 (lat) X 165 (lon) grid points. We initialize simulations on 1 October 1996 to spin-up soil moisture. Our focus period is May-August 1997.

An important feature of the Grell-Pagowski version of MM5 is its parallel computing capability. We have exploited this on an 8-processor cluster at Iowa State and, more important, a multi-processor Linux cluster at Argonne National Laboratory that Dr. John Taylor has made available to MM5 collaborators. (Dr. Taylor has interacted with Iowa State on the Project to Intercompare Regional Climate Simulations [PIRCS], which is supported by another NOAA grant.). The domain size requires prohibitive computation time on a serial machine. Cluster simulations have allowed us to perform timely initial spin-up and baseline simulations (Table 1). They will also allow us to perform higher resolution nesting and sensitivity simulations that evaluate the significance and interaction of various physical processes and improve simulation. Comparison of output from computations using different numbers of nodes shows no difference in the evolution of domain averaged daily precipitation, so inter-node communication introduces no differences in numerical details such as summations, products, etc.

Table 1 - Computation rates for the 5-km MM5 Kansas domain

# cluster nodes	wall-clock time [hr] /simulated month
8 (ISU)	120
32 (Argonne)	27
64 (Argonne)	17

The simulations have shown substantial promise. Key features of the Kansas region are its relatively flat terrain and significant summer precipitation from convective storms. Thus, gains from using high resolution must come not from better resolution of topographic control of precipitation but from better simulation of temporally and spatially variable atmospheric dynamics. For the region inside the model's forcing frame, where it ingest lateral boundary conditions, the model simulates the cumulative precipitation for May-August within 20% of the CPC 0.25° gridded observations (Fig. 1). The gridded CDC observations have not been corrected for gauge undercatch, which may give measured values a negative bias of 3 – 10%. The model also captures high intensity events (Fig. 2), which are important for modeling the land-surface hydrology properly. Note that the CDC observations are gridded on a coarser grid than the model output. We expect a closer match when we smooth the model output to a 20 or 25 km grid.

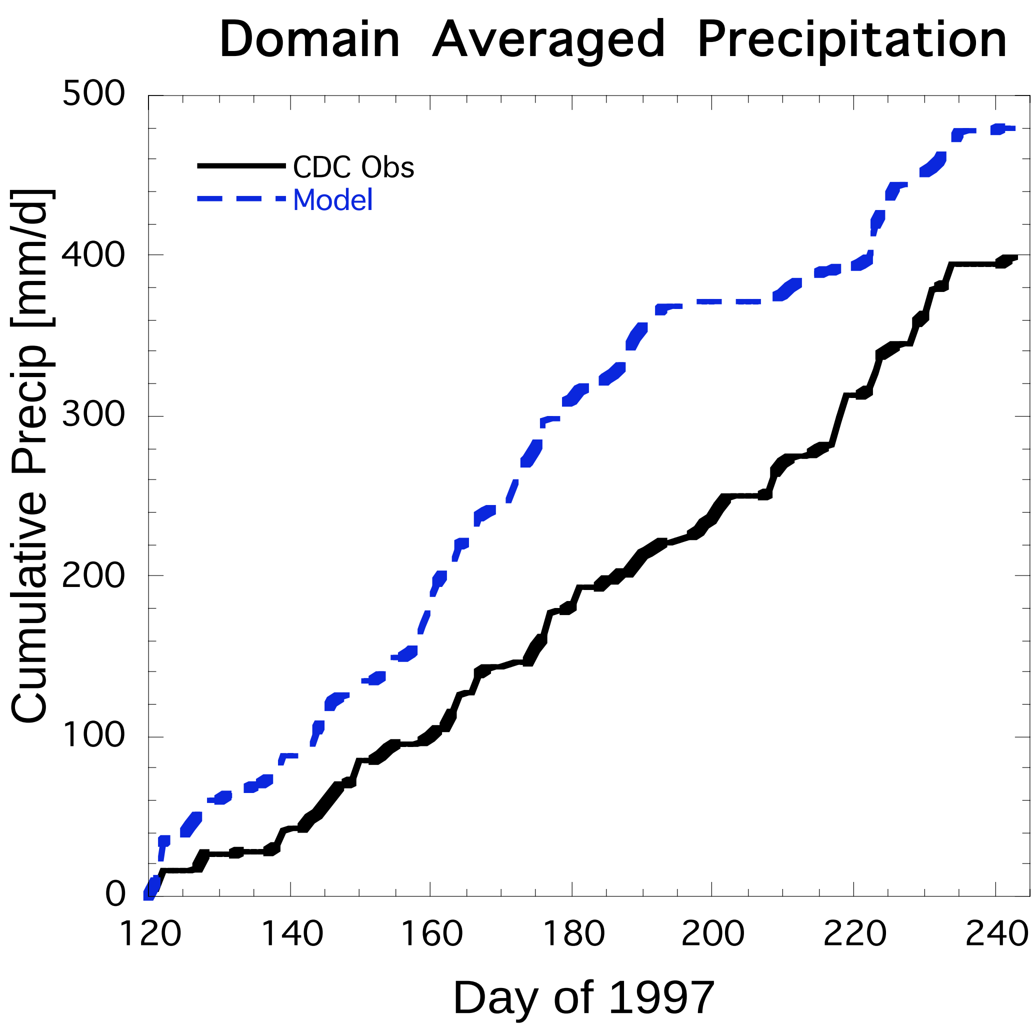

Fig. 1 – Cumulative daily precipitation averaged over the model domain inside the forcing frame.

3. Future Work

3.1 Off-line simulations with land-surface and hydrologic models

We will extend our current work in the Yampa and Walnut River basins to explicitly examine the value that is added (or lost) with greater model complexity. This will be achieved using a building-block approach—start with a simple lumped hydrologic model with no vegetation schemes or ET routines (the Sacramento model)◊ distributed version of the Sacramento model◊ add ET routines and vegetation◊ more explicit treatment of the surface energy budget (the Catchment LSM). All models will be put on equal footing through extensive calibration of model parameters.

A similar approach will be applied to the high-resolution coupled MM5 output. The two end-points will be (1) using MM5 precipitation and temperature simulations as input to a conceptual hydrologic model and (2) replacing conceptual hydrologic models estimates of surface and sub-surface runoff with the MM5 output of those quantities.

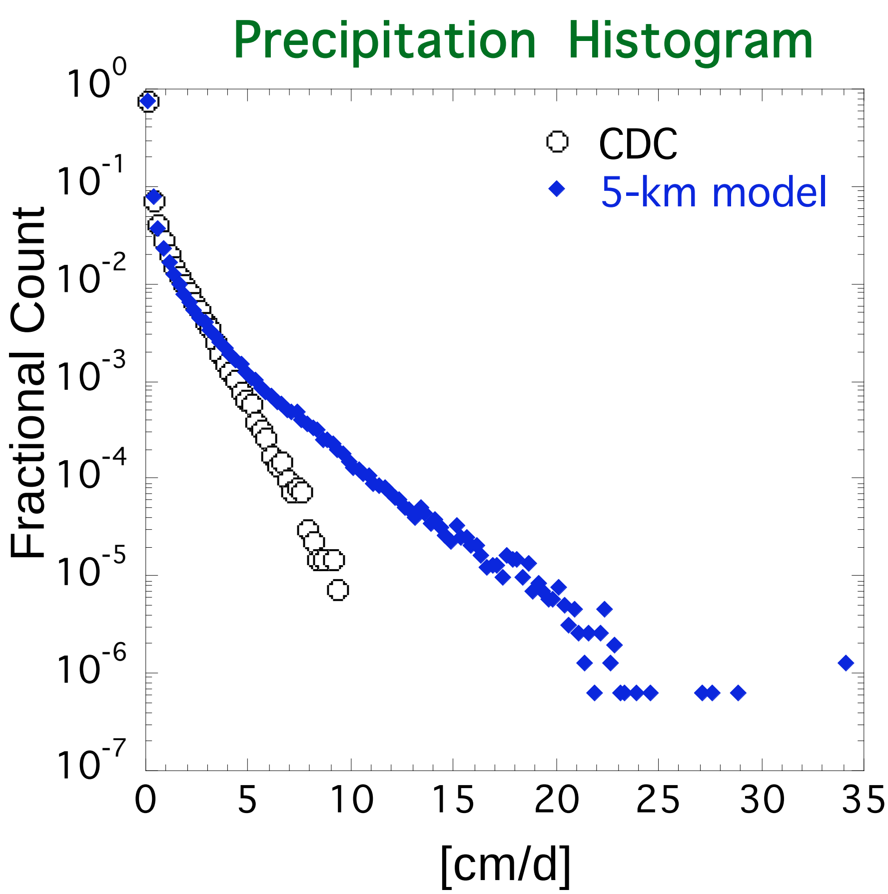

Fig. 2 – Precipitation intensity histogram for daily precipitation at CDC and model grid points. CDC values are observations on a 1/4 degree grid.

3.2 High-resolution coupled runs with MM5

We will continue analysis of the climatology of the 5-km simulations for Kansas. Questions requiring answers include:

- Does the 5-km grid improve the overall spatial and temporal evolution of precipitation simulation compared to the parent 20-km grid simulation?
- Does the 5-km grid improve the diurnal cycle of precipitation compared to coarser resolution? (This will require hourly observations.)
- How sensitive is the precipitation simulation to adjustments of cloud microphysical parameters within their uncertainty?
- Is the simulation producing dynamics characteristic of mesoscale convective systems?
- Does yet higher resolution (planned 1.7 km) give further improvement?
- How accurate are hydrology simulations using the MM5 Kansas output?

4. Publications from this project

Two papers supported by this project but based on work performed primarily under a previous NOAA grant have been conditionally accepted for publication:

(1) Gutowski, W. J., F. Otieno, R. W. Arritt, E. S. Takle and Z. Pan, 2003: Diagnosis and attribution of a seasonal precipitation deficit in a U.S. regional climate simulation. *J. Hydrometeor.* (accepted pending minor revision).

Precipitation from a 10-yr regional climate simulation was evaluated using three complementary analyses that all reveal a precipitation deficit in the south central United States that emerges in September and lingers through February. Analysis of terrestrial and atmospheric water balances shows that the 10-yr average precipitation error for the region results primarily from a deficit in horizontal water vapor convergence. However, the 10-yr average for fall only suggests that the primary contributor is a deficit in evapotranspiration. Evaluation of simulated temperature and soil moisture suggests the model has insufficient terrestrial water for evaporation during fall. Results for winter are mixed; errors in both evapotranspiration and lateral moisture convergence may contribute substantially to the precipitation deficit. The model reproduces well both the time-average and time-filtered large-scale circulation, implying that moisture convergence error arises from error in simulating mesoscale circulation. Deficient precipitation for this region and time of year is also evident in other simulations, indicating a generic problem in climate simulation.

(2) Gutowski, W. J., S. G. Decker, R. A. Donavon, Z. Pan, R. W. Arritt and E. S. Takle, 2003: Temporal-Spatial Scales of Observed and Simulated Precipitation in Central U.S. Climate. *J. Climate* (accepted pending minor revision).

Precipitation intensity spectra for a central U.S. region in a 10-yr regional climate simulation are compared to corresponding observed spectra for precipitation accumulation periods ranging from 6 h to 10 d. Model agreement with observations depends on the length of precipitation accumulation period, with similar results for both warm and cold halves of the year. For 6-h and 12-h accumulation periods, simulated and observed spectra show little overlap. For daily and longer accumulation periods, the spectra are similar for moderate precipitation rates, though the model produces too many low-intensity precipitation events and too few high-intensity precipitation events for all accumulation periods. The spatial correlation of simulated and observed precipitation events indicates that the model's 50-km grid spacing is too coarse to simulate well high-intensity events. Spatial correlations with and without very light precipitation indicate that coarse resolution is not a direct cause of excessive low-intensity events. The model shows less spread than observations in its pattern of spatial correlation versus distance, suggesting that resolved model circulation patterns producing 6-hourly precipitation are limited in the range of precipitation patterns they can produce compared to the real world. The correlations also indicate that replicating observed precipitation intensity distributions for 6-h accumulation periods requires grid spacing smaller than about 15 km, suggesting that models with grid spacing substantially larger than this will be unable to simulate the observed diurnal cycle of precipitation.

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